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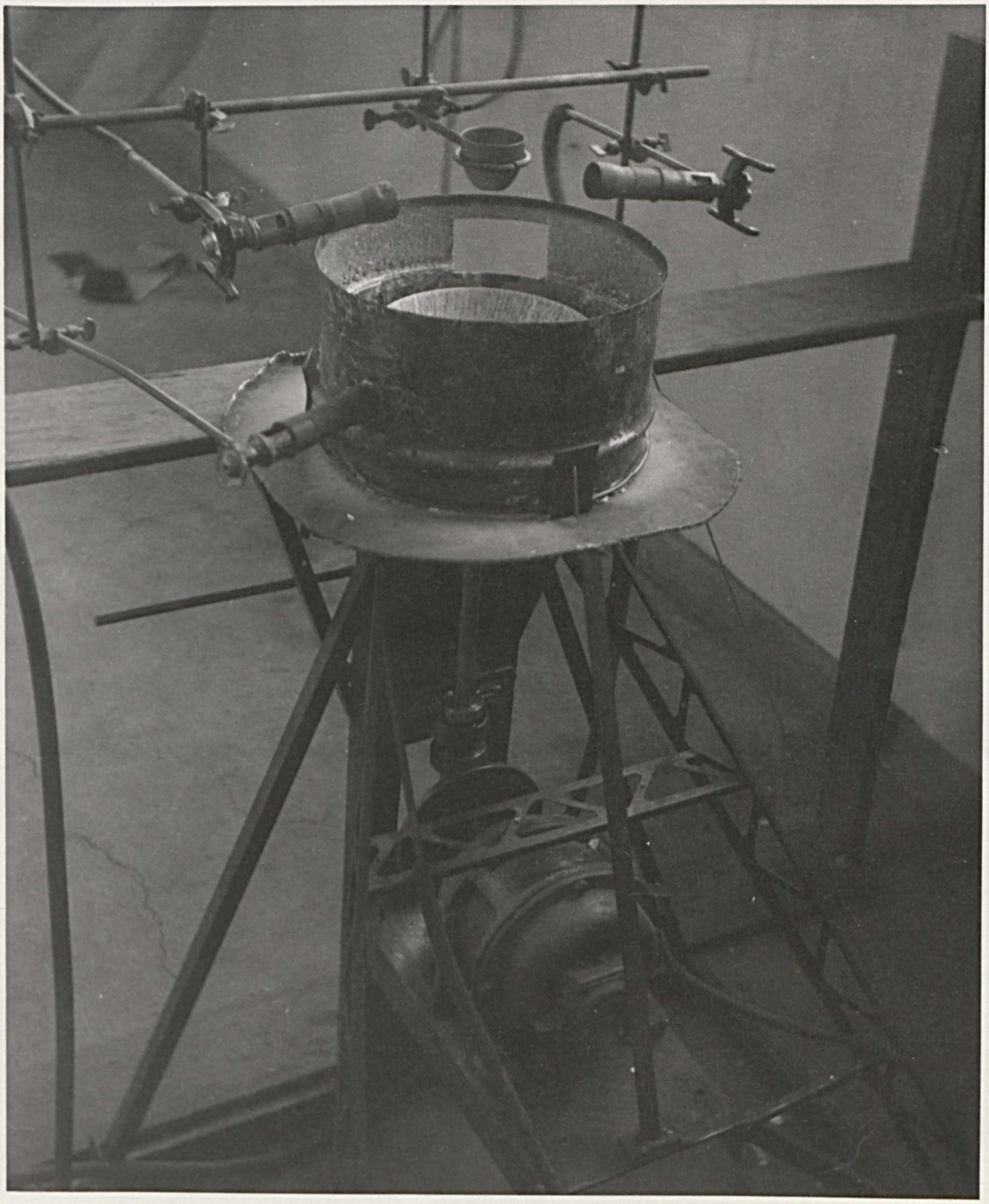

The experimentation for the problem described in this paper was conducted as a combination of the efforts of Mr. Robert Payne and Mr. Charles Schroer.

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I ABSTRACT

The object of this thesis is to produce zinc dust suitable for zinc leach purification, by direct application of a mechanical force on a stream of molten zinc.

The project is a continuation of work done by Mr. D. S. Gleason, while working for his Master of Science degree in the spring of 1952.

The apparatus used in this project was designed and assembled in the Metallurgy Department of the Montana School of Mines and consists of a horizontal cast-iron plate driven by an electric motor with a right angle plate and wheel clutch. The wheel is mounted on a shaft, which in turn is secured to an angle iron frame bolted to a concrete floor.

From the observation of several of the variables that effect the quality of the dust produced, it was concluded that the following conditions gave best results:

1. Surface of the plate should be the shape of an inverse cone or parabola.

2. Temperature of the plate should be just above the melting point of zinc.

3. Molten zinc should be fed to the existing apparatus at a rate of one to two tons per day.

II INTRODUCTION

Zinc dust used for the displacement of copper and cadmium in the purification step of zinc leaching should be free from impurities, unoxidized, and have a large surface area per unit volume.

The most common method employed to day for the production of zinc dust is by air atomization. In this process a blast of compressed air is directed upon a thin stream of molten zinc with disintegration caused by the impact of the high-speed air on the stationary metal. The product thus produced can be as fine as 35% -200 mesh, with very little + 35 mesh material.

The object of this project is to produce a zinc dust comparable to that produced in the atomization process by using an apparatus that causes disintegration by mechanical forces acting upon a stream of molten zinc.

A stream of molten zinc is played upon a horizontal plate with inclined sides revolving at high speeds. The zinc is thrown from the plate by centrifugal force, and disintegration is caused by the impact of the zinc with the cool still air about the periphery of the wheel.

III THEORY

The explanation of why zinc dust is produced by the method presented here can best be illustrated by showing what will happen to a film of liquid, when it is poured from the edge of a vessel in a thin, flat stream. If the film is very thin, it will disintegrate, and the surface tension of the liquid will cause the formation of many short spherical droplets. If velocity is imparted to these droplets disintegration will continue.

Although this explanation of why the metal dust can be produced sounds simple, there are many factors effecting the quality of the final dust product, and any calculation of actual size of the product obtainable is impossible.

The average size of the metal dust product is dependent upon two factors, namely, the thickness of the metal film as it leaves the surface of the plate and the velocity at which the metal impacts with the still air around the plate. The forces that have the greatest effect upon these two factors are the centrifugal force caused by rotation and the surface tension of the metal. When a film of molten metal is conveyed along the surface of the plate by centrifugal force, the thickness of the film of metal is determined by the rate of feed of that metal. If the metal is fed at a rate slow enough that the metal tends to leave the plate more quickly than it is fed to it, the thickness of the metal film will be determined by its surface tension.

From this discussion it follows that with a less than critical feed rate on a flat plate, the thickness of the metal film will remain nearly the same regardless of the rotating speed.

If a plate is used that has inclined sides the centrifugal force, which is always normal to the direction of motion, will be resolved into two components--one parallel to the inclined surface and one normal to this surface. As can be seen by Fig 2, if the angle of incline with the horizontal is smaller than 45^{o}, the normal force is smaller than the parallel force. If the angle is greater than 45^{o}, the normal force will be greater than the parallel force.

We can see that when metal is fed to this plate at a rate below the critical rate, the normal centrifugal force will tend to overcome part of the surface tension of the metal and cause the film to be thinner; the parallel force will propel the film along the incline.

It follows from this discussion that if a plate with inclined sides at a constant rotation speed, and feed rate below the critical amount to cover the wheel is used, the thickness of the film will be inversely proportional to the angle of inclination. Also, if the velocity is varied, the inclination of the plate is held constant, both normal force and parallel force will increase as velocity increases; thus, the film thickness will decrease as rotating speed is increased.

The velocity of a particle, the instant it leaves the circumference of the disk, is the result of two factors. (1) Rotational velocity of the wheel imparts that same velocity to the particle in a direction tangential to the circumference of the wheel. (2) Velocity is imparted to the particle by the centrifugal force of the rotating object. This force acts normal to the tangential velocity. A calculation of this nomal velocity may be accomplished in the following manner:

Visualizing a particle of molten metal the instant it breaks contact with the plate, we will find that two forces are acting. Surface tension (F_s) of the metal film acting to hold the particle to the film, and centrifugal force (F_c) acting to pull the particle away from the wheel.

$$F_c - F_s = F_V$$

$$F_c = \frac{M\,v^2}{r}$$

$$F_V = \tfrac{1}{2}\,M\,V^2$$

where

$M =$ mass of the particle

$r =$ radius of the wheel

$v =$ rotational velocity of the wheel

$V =$ normal velocity of the particle

therefor

$$\tfrac{1}{2}\,M\,V^2 = \frac{M\,v^2}{r} - F_s$$

$$V^2 = \frac{2\,v^2}{r} - \frac{2F_s}{M}$$

At 3000 RPM

$$V^2 = \frac{2\,(3990)^2}{12.7} - \frac{1416}{M}$$

The factor, mass, is unknown, so for the time being if we neglect the last factor, we find that disregarding surface tension the normal velocity is equal to 1570 cm/sec or 52 ft/sec.

Rotational speed of 3000 RPM gives a particle tangential velocity of 131 ft/sec, when a plate 10 in. in diameter is used. Since the tangential velocity and the normal velocity are 90° apart, the direction the particle takes leaving the plate is that of the resultant of the two velocities. Resolving 131 ft/sec for the tangential velocity and 52 ft/sec for the normal velocity, the resultant path of the particle is 22° from the tangent of the circular plate.

Observations of the direction of the particle leaving the wheel showed it to be leaving almost directly along the tangent of the plate. From this observation, it was decided that the force of surface tension is very nearly the same as the centrifugal force; therefore a normal velocity of 15.7 cm/sec is probably more nearly the correct value than is the maximum.

The thickness of the metal film on the outer circumference of a rotating plate is dependent upon the rate at which the metal is fed to the plate and the rotating speed. With this in mind, it is now possible to calculate the thickness of a continuous metal film at the point it is leaving the plate. The thickness can be arrived at through the following relationship:

$$T = \frac{r}{dcv}$$

where

$T =$ thickness of the film

$r =$ rate of feed (10 gm/sec)

$c =$ circumference of the plate (79.8 cm)

$v =$ normal velocity of the particle (15.7 cm/sec)

$d =$ density of molten zinc ($6.48\ gm/cm^3$)

$$T = \frac{10}{6.48 \times 79.8 \times 15.7}$$

$T =$ 123 microns

This treatment can be considered as little more than a sample calculation, because we have no way of knowing how accurate the normal velocity is; but if one reverses these steps, taking an observed value for the thickness of film to be 75 microns at a feed rate of 1gm/sec, it is possible to calculate "mass" in the velocity equation.

$$V = \frac{r}{Tdc}$$

$$V = \frac{1}{6.48 \times 79.8 \times .00075}$$

$V =$ 2.58 cm/sec

substituting into velocity equation,

$$\frac{2\ F_s}{M} = \frac{2v^2}{r} - V^2$$

$$\frac{2\,F_s}{M} = 2.5 \times 10^{-6}$$

$$M = \frac{1416}{2.5 \times 10^{6}}$$

$$M = .00057 \text{ gm}$$

A zinc sphere of this weight would just pass through a 35-mesh screen. If a teardrop shape were assumed, which is closer to the observed shape, the diameter would be smaller. Also, it is necessary to point out that the surface tension (F_s) is in dynes/cm; so mass (M) is the mass of all the zinc comming off a 1 cm segment of the circumference at any instant. The actual number of particles comming from thic section would depend upon several of the other factors effecting the size of the particle.

Diagram of Apparatus Used

in Zinc Dust Problem

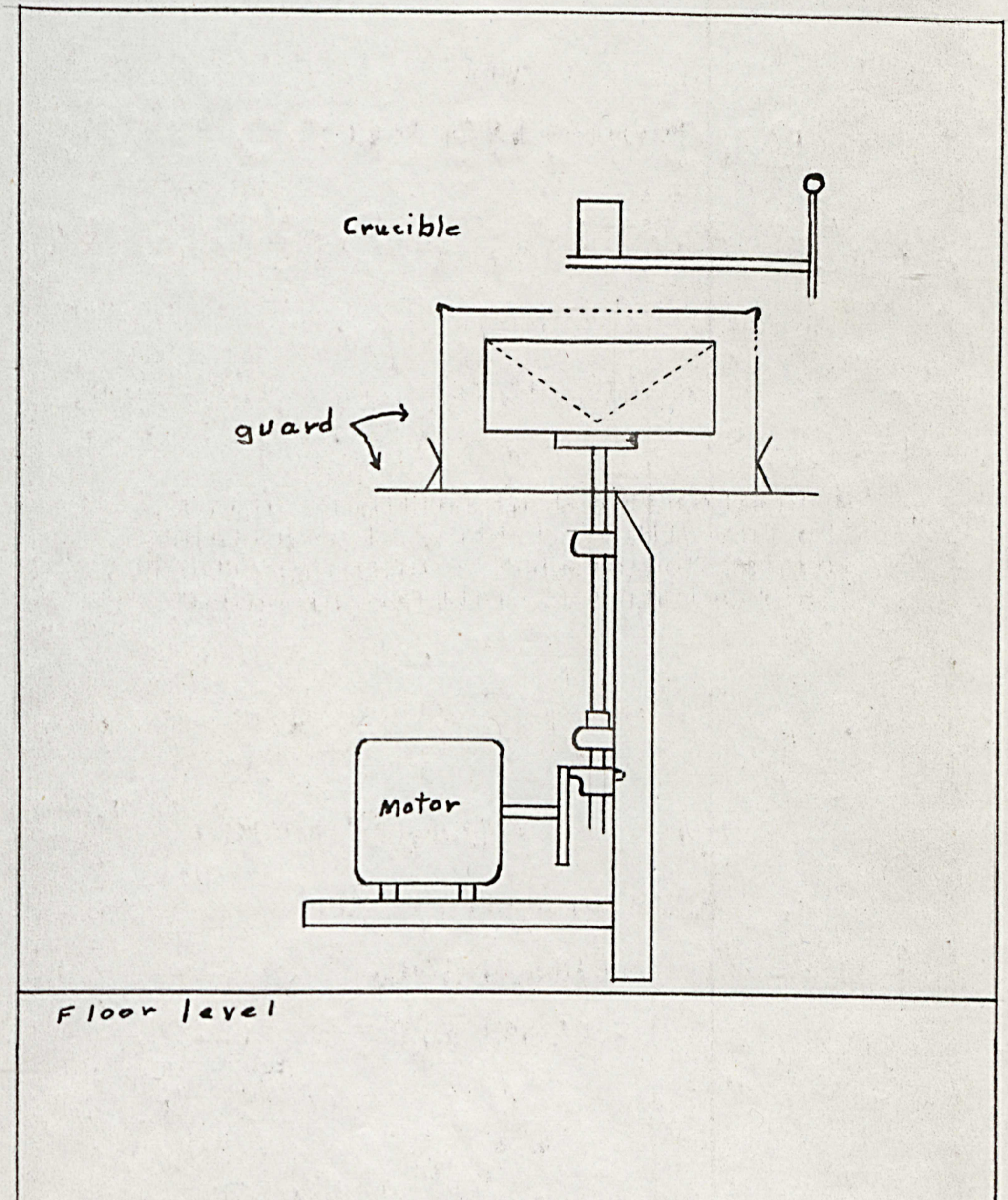

Fig 1

Plates used in this Problem

Showing Centrifugal Force Vectors

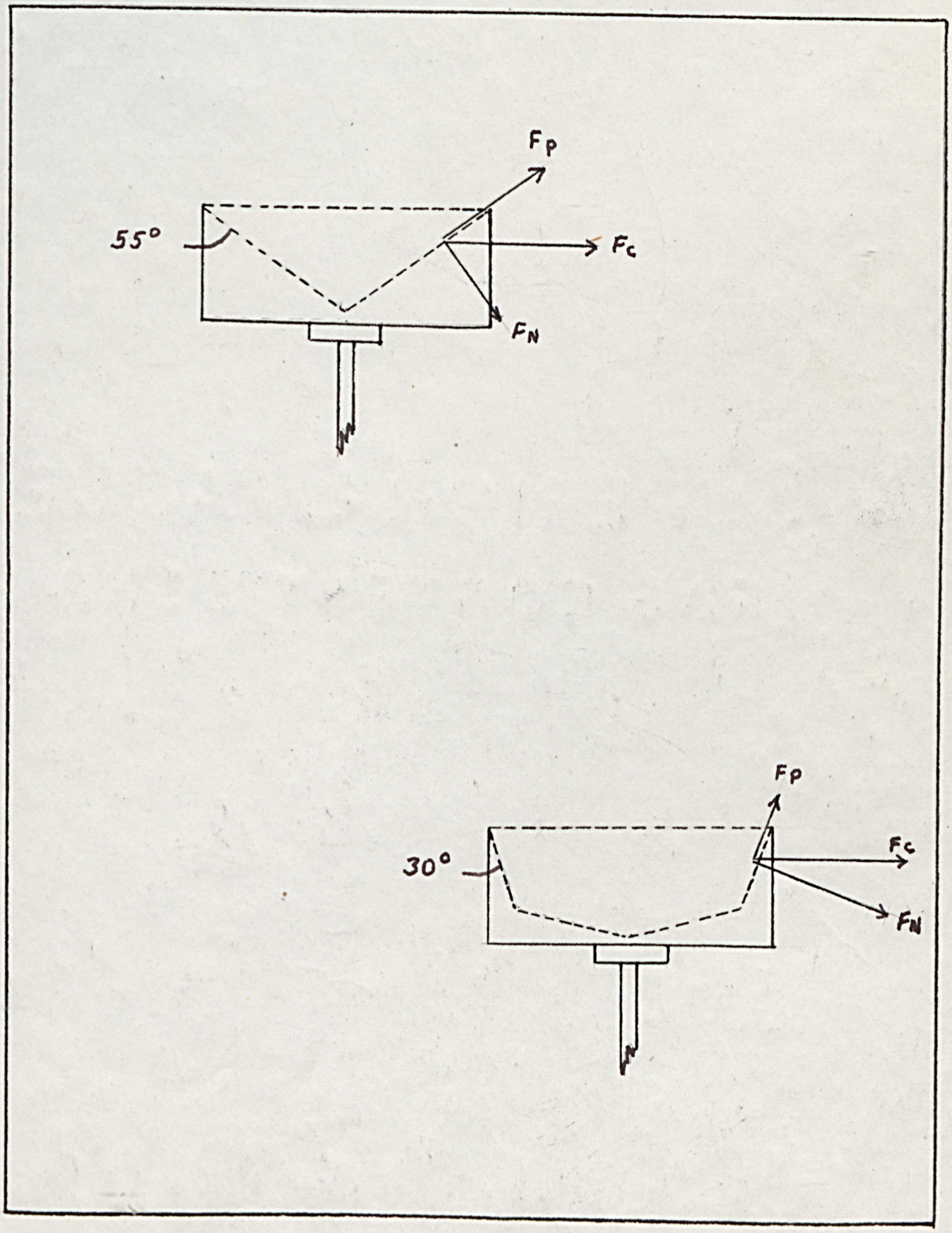

Fig 2

IV DISCRIPTION OF APPARATUS

The dust producing machine was designed and assembled in the Metallurgy Department of the Montana School of Mines. The machine consists of a 10 in. machined cast iron disk driven by an 1800 R. P. M. motor with a right angle plate and wheel drive. The apparatus is mounted on an angle iron framework, securely bolted to studs set in the concrete floor. A shield, approximately 20 in. in diameter, consisting of iron sheet metal is welded to the angle iron frame, one inch below the cast iron disk, to shield the assembly from molten zinc. The disk is 10 in. in diameter and 4in. thick. The upper surface is coned inversely at an angle of 35° from the horizontal. This disk weighing about 45 lb is connected by collar and bolts to a vertical steel shaft 24 in. long and 1 in. in diameter. The entire assembly is held in place by two thrust bearings bolted to the frame.

The weight of the moving parts is supported on the lower bearing with a collar attached to the shaft and resting on the inner race of the bearing. The drive consists of a vertical, circular plate on a shaft from the motor and a wheel concentric with and mounted on the vertical shaft. The speed ratio can be changed by raising or lowering the wheel with respect to the vertical plate.

A cylindrical shield, for protection of the individuals standing around the machine, while it is running, is mounted around the cast iron disk and is resting on and attached to the horizontal shield. The cylindrical shield is slotted at the upper circumference of the disk to allow a sample of the metal dust to be collected. The slot is cut with dimensions equal to 10% of the total circumference of the shield, thus allowing 10% of the metal dust to be collected.

All auxiliary apparatus such as crucible, burners, and holders are mounted to horizontal pipe, bolted to the two opposite walls of the room. This arrangement leaves auxiliary equipment free from the vibration incured in the rotating disk.

Crucibles used are graphite, alundum, iron, and magnesia. The sample is collected on oil cloth suspended from a wooden frame. The top bearing is cooled by a stream of air. No cooling is needed for the lower bearing.

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V OPERATING PROCEDURE

To make a "run" in this project with the least amount of confusion and loss of time, it was found necessary to plan the runs to give maximum utilization of time and minimum confusion. With these factors in mind, the following operating procedure was developed:

First the electric furnace was turned on, and the zinc metal was placed inside in silica crucibles. While the zinc was melting,the plate was heated by directing two burners against it. The temperature of the plate was measured at different intervals by placing wires from a standardized thermolcouple in a small well drilled in the upper circumference of the plate. When the plate was heated to the desired temperature, the crucible was placed in the clamp directly above the center of the plate, and one of the burners was taken from the plate and played on the crucible. The machine was then greased and turned on, and the clutch was engaged by tightening oneof the fromt motor mounting bolts. About two minutes was allowed for the plate to get up speed, at which time the remaining plate burner was also played on the crucible. At the same time the top of the housing was put in place and the molten zinc was removed from the furnace. The molten zinc was poured into the crucible and allowed to flow through the aperture. A guard was held over the opening in the housing until the metal started to flow uniformly. The length of time was measured with a stop watch.

Upon completion of the run, the dust was collected from the oilcloth target and placed in sample envelopes to be later screened and analysed.

VI DATA

To obtain understandable data for this work, it was necessary to ascertain, at the start, what the variable conditions were, and which could be varied to give a more clear plan for efficient commertial application. The following conditions were considered for variation:

1. Surface of the plate.
2. Temperature of the plate.
3. Temperature of the zinc.
4. Rate of feed to the plate.

Work done by Mr. Gleason, and theoretical considerations offered in this paper, show that the plate must be coned inversely for best results. The two plates used in this project are shown in Fig 2.

The initial temperature of the zinc was found to be a factor of little consequence to the actual size of dust, because the thin film of zinc on the plate immediatly takes on the temperature of the plate. An arbitrary temperature of 1100° F was selected to give satisfactory pouring characteristics.

?The temperature of the plate was varied between 800° F and 1100° F, and the rate of feed between .133 ton/day and 3.66 ton/day. Fig 3 and Fig 4 illustrate general trends found in the data. Table 1 gives all the data from the 16 sucessful runs.

Plotting

Rate of Feed vs Particle Size

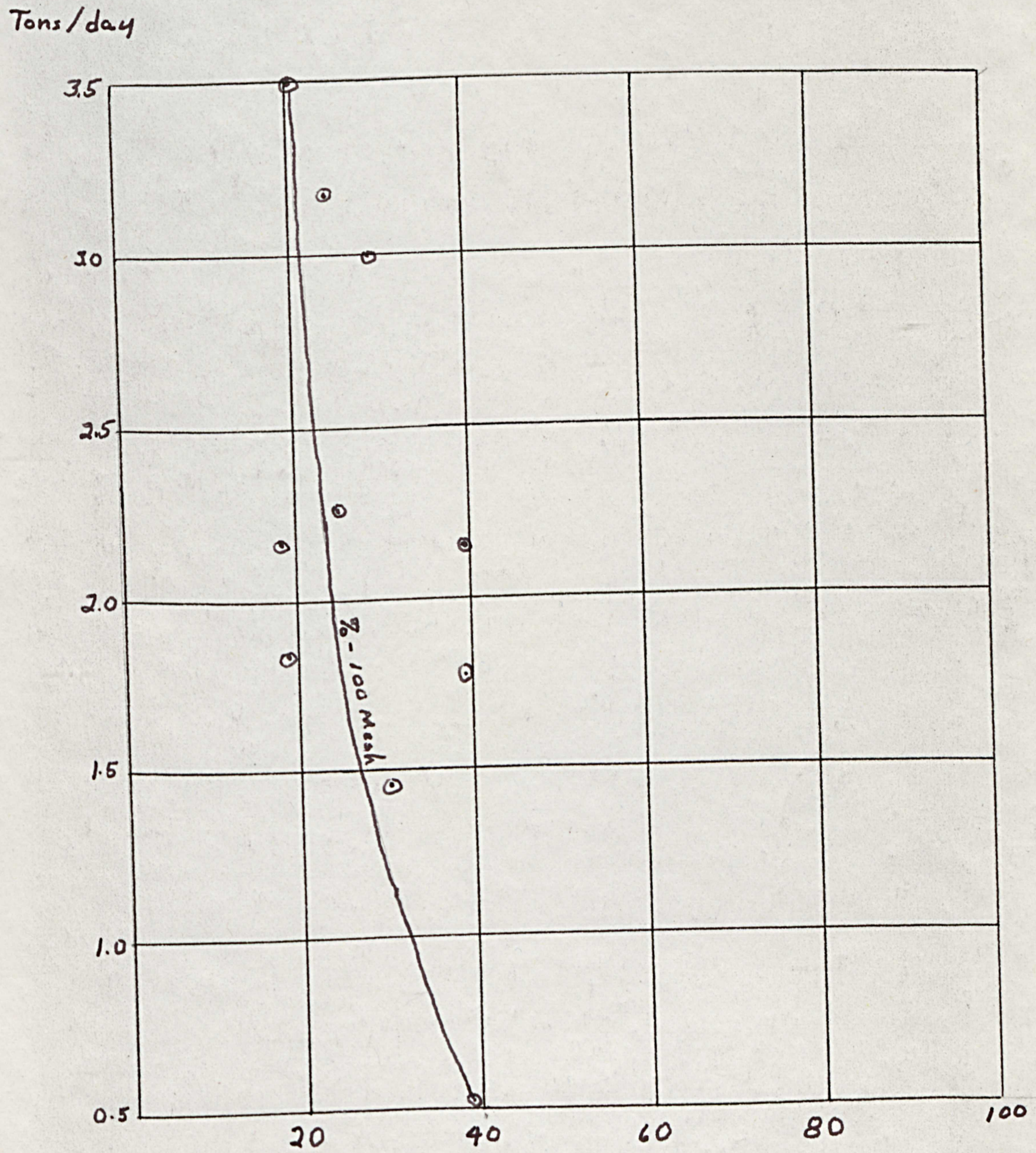

Fig 3

Plotting

Plate Temperature vs Particle Size

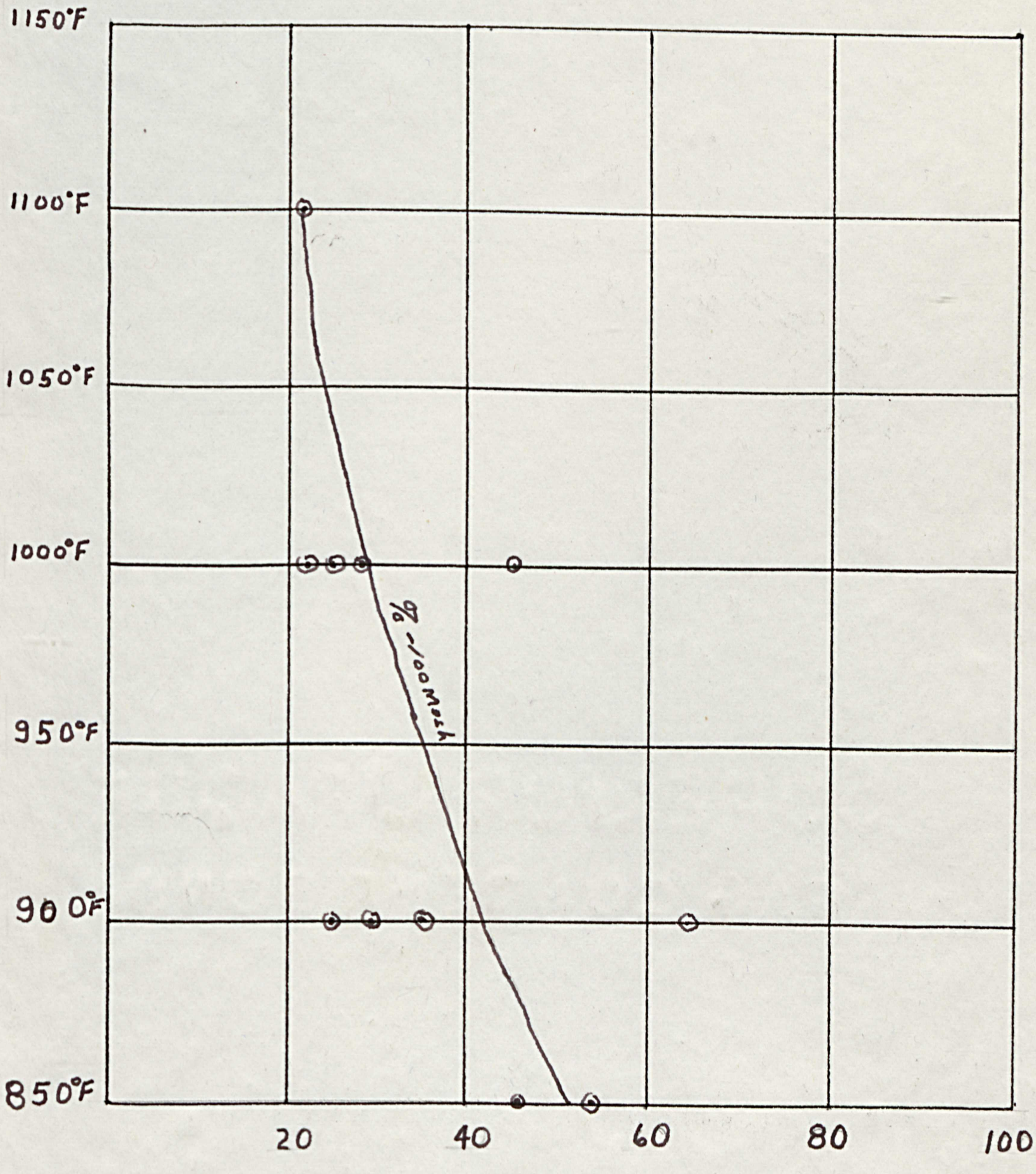

Fig 4

Tabulated Data of the Successful

Experiments

Sample Number	Temperature	Feed in Tons/day	Percent Passing Through (Mesh) 35	65	100	200
5	800	0.70	87	57	37	18
8	800	1.07	100	90	56	36
9	800	2.14	86	58	38	21
1	900	0.75	100	80	61	22
3	900	1.45	100	62	26	7
12	900	2.17	91	64	17	4
10	900	?	84	75	31	6
11	950	0.33	100	88	24	5
13	950	0.95	100	94	38	5
16	950	2.20	91	68	25	8
14	1000	0.93	100	93	32	4
2	1000	1.75	100	84	36	9
7	1000	2.34	79	40	23	10
4	1000	3.66	96	64	20	5
15	1100	0.70	100	87	23	4
6	1100	1.83	69	30	17	8

Data Arranged in Order of Increasing Disk Temperatures And Rates of Feed

Table 1

VII INTERPRETATION OF DATA

General trends as shown by Figs 3 and 4 show that with decreasing plate temperatures, average particle size decreases, and with decreasing rate of feed average particle size also tends to decrease. These trends follow theory closely, except, it would be expected that the reverse would be true with respect to the plate temperatures. Perhaps the effect of lower surface tension caused by higher temperatures will be overcome by the effect of decreased viscosity of the metal, which would cause higher normal velocities and possibly more zinc per particle.

Runs, 13, 14, 15, and 16 were made with a plate whose sides were sloping at 60° with a base sloping 9° to the center. As one can see from Table 1 the products from these four runs are more uniformly sized than are those made with the first plate surface. Also, the average particle size of these products is smaller. A smaller product is understandable because the greater slope on a plate will cause thinner films and therefore smaller dust.

Perhaps the most interesting phenomenon encountered with the new plate surface is the previously mentioned uniformity of size of the product. It is axiomatic that when a container containing liquid is rotated at high speeds, the liquid in that container tends to assume a parabolic shape; because of the variation in centrifugal force subjected on the liquid from the center of the container to the outer edge.

Theorizing from the preceding paragraph, one could say that the uniformity of size encountered with the last plate surface, that is the plate with the more nearly parabolic shape as can be seen in Fig 2, is a function of that parabolic shape.

VIII CONCLUSION

The process for producing zinc dust described in this paper seems to be definitely amenable to commertial application in the purification of zinc leach solutions. Instalation of apparatus of this type would present no difficulty and according to calculations made by Mr. Gleason (1, p 26) the dust could be produced much more economically than with the present method of air atomization.

Results of this project give the following indications:

1. The operating temperature of the plate must be above the melting point of zinc; although, higher temperatures than that will cause courser dust.

2. For best results the surface of the plate must be in shape of an inverse cone or parabola, with greater angles of slope causing finer dust.

3. Increased rotational speeds of the plate cause the production of finer dust, and greater production is obtainable.

4. Plates with larger diameters allow greater production with finer dust.

A large amount of research could be done with this project. It is recommended that the future work be conducted using much greater rotational speeds and greater variation in plate surface shapes, with a complete study of the surfaces with parabolic shapes.

X ACKNOWLEDGMENT

The author of this paper would like to take this space to express his sincere appreciation for the time and effort extended by Dr. J. George Grunenfelder, Dr. Frederick A. Hames, and Mr. Ralph I. Smith, all members of the staff of the Metallurgy Department of the Montana School of Mines.

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